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FINAL REPORT
INSTRUMENTATION DEVELOPMENT
OF AN
AIRBORNE RECORDING SYSTEM

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A Methodology Investigation of an airborne recording system was conducted at US Army Yuma Proving Ground (YPG), Arizona, from November 1976 through December 1977. This new system has been developed by the Air Delivery Engineering Branch at YPG for recording and processing accelerometer vibration spectral data in support of materiel air transportability and air delivery testing missions.

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20. ABSTRACT (Concluded)

The new data processing is based on a programmable calculator and suitable peripheral equipment. Accelerometer time histories from an analog recorder are digitized and processed on the programmable calculator system. Software provides for Fast Fourier computation of Power Spectral Density functions, acceleration and double amplitude displacement curves. The computed functions are displayed on an impact line printer for report mat printing. Hardware and software implementation of the new instrumentation system are described.

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SECTION 1. SUMMARY

1.0 BACKGROUND

The U.S. Army Yuma Proving Ground (YPG) air delivery test mission includes both air drop and air transportability tests under the general connotation of Air Delivery. Tests are conducted using three separate drop zones for dynamic testing from aircraft, and a controlled impact facility for static drop testing. The drop zones are designed for explosive devices, nonexplosive devices, and personnel.

The Naval Air Facility at El Centro, California (93 miles from YPG) offers facilities to supplement and extend the YPG capabilities. YPG also conducts tests in nearby Senator's Wash Reservoir on the Colorado River for the conduct of water impact tests.

In addition, YPG provides both personnel and instrumentation to support air delivery tests at other installations such as Fort Bragg, North Carolina; Fort Carson, Colorado; and White Sands Missile Range, New Mexico.

The YPG air transportability (internal/external) mission is becoming increasingly important and its workload increasing accordingly. Major tests in this area include the FAMECE (Family of Military Engineers Contractor Equipment) Test Series, the UET (Universal Engineer Tractor) Test Program, the Battery Control System Test Program and the Armor Personnel Carrier Test Series.

The existing vibration data analysis is done by two different groups at YPG. The accelerometer instrumentation and playback is handled by the Electronics Section with the use of the usual airborne and laboratory magnetic tape recorders, oscillographs for time history editing, and a narrow-band spectral analyzer. The detailed data analysis is accomplished by the Data Reduction Section on an as-available class service, which usually takes several weeks.

Even longer times are involved when air transportability tests terminate at bases other than YPG, and the data tapes must be brought back to YPG before any data reduction analysis can be performed.

The long analyzer computation time, the resulting lack of data analysis flexibility, and the desire to give the project engineer a choice in data formats has led to the development for a small dedicated system that could be operated in the field.

A Methodology Investigation of an airborne recording system developed by the Air Delivery Engineering Branch, YPG, was conducted from November 1976 through December 1977.

2.0 OBJECTIVE

This report describes the hardware and software implementation of an airborne recording system for recording and processing accelerometer vibration spectral data from air delivery and transportability tests of Army materiel. The system is based on a programmable calculator and record/reproduce instrumentation. An HP9825A calculator, HP9871A impact line printer, and interface electronics were integrated with an analog 14-channel magnetic tape recorder/reproducer to digitally process and print/plot acceleration, power spectral density and displacement versus frequency from several triaxial accelerometers. The system is an outgrowth of a long standing requirement of the Air Delivery Engineering Branch of YPG for a portable, stand-alone system for air transportability testing of army materiel test items to AR 70-41 standards.

3.0 SYSTEM DESCRIPTION

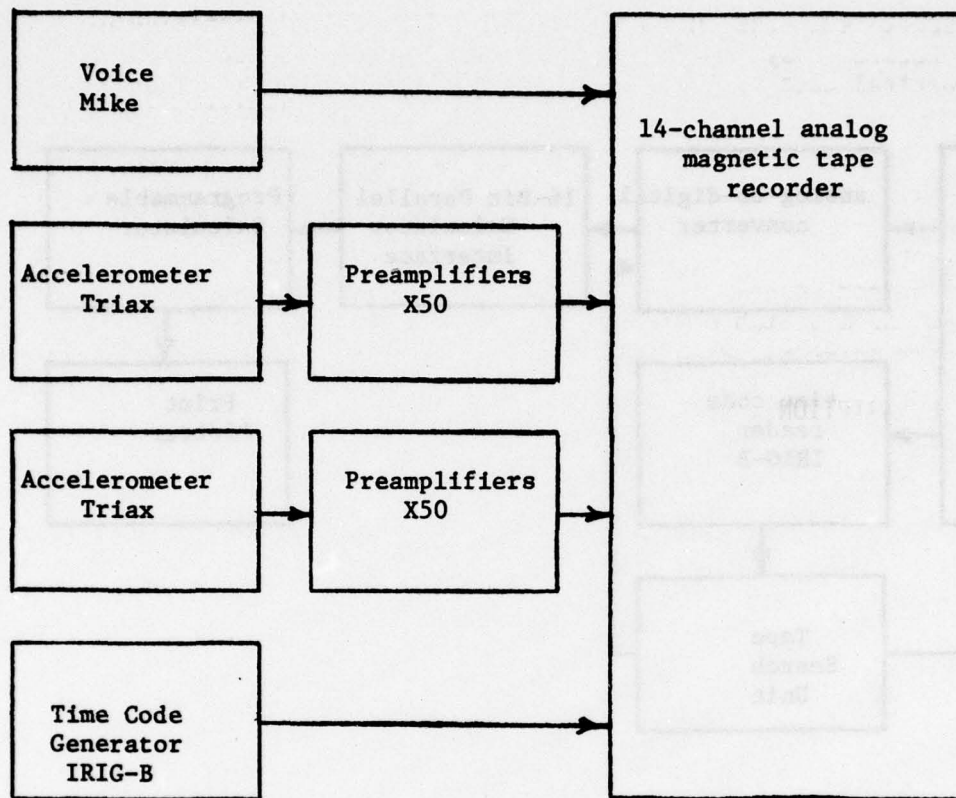
3.1 Summary

The programmable calculator-based vibrational analysis system can best be understood by studying the block diagram illustrated in Figures 1 and 2.

First there is a data acquisition phase (Fig. 1) where the outputs from the triaxial accelerometers are recorded on magnetic tape for later data analysis. At the same time IRIG-B time code and any voice annunciation signals are also recorded for the purpose of knowing where to index into the tape to find the data of interest. All of this equipment is capable of operating off 28-volt dc aircraft power.

Next, there is a data analysis phase (Fig. 2) where the analog data from the magnetic tape reproducer is digitized for input into the programmable calculator. Furthermore, the system makes use of a tape search subsystem to find starting and ending points of data channels for an operator's predetermined time. This subsystem uses the IRIG-B time code channel recorded in the data acquisition phase for this information.

The digitized accelerometer data read into the calculator is then transformed into the frequency domain by use of a Fast Fourier transform program. This program outputs power spectrum versus frequency information to several plotting routines for different plotting formats. These plots are then outputted to an impact line printer for display to the project engineer.



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Figure 1. Data Requisition Phase

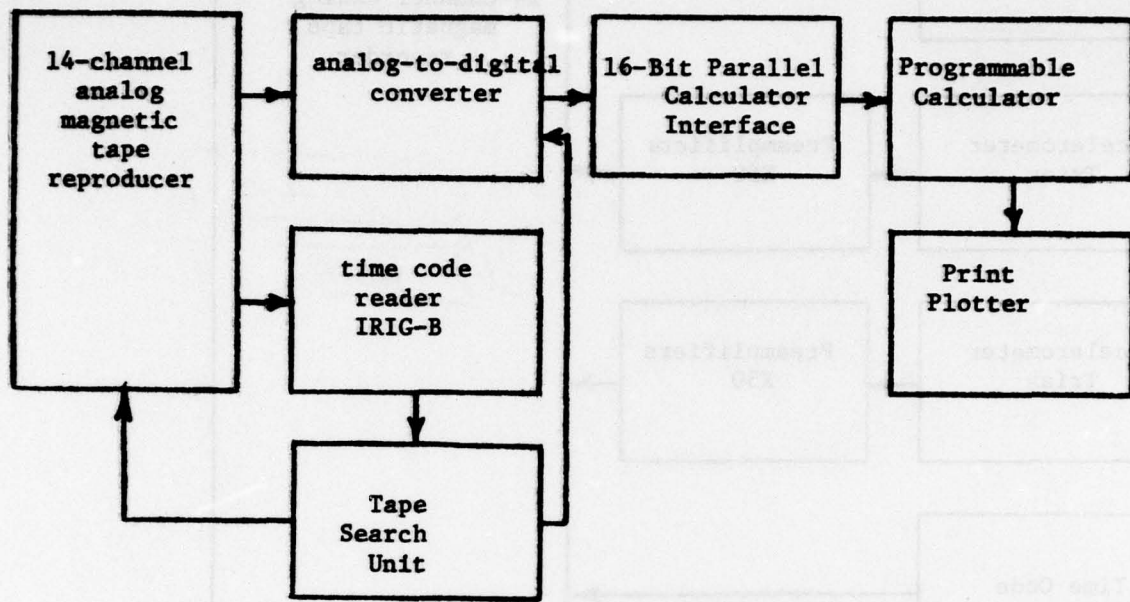


Figure 2. Data Analysis Phase



FIGURE 3. Configuration of the Hewlett-Packard 9825 calculator and peripheral equipment.

3.2 Hardware

3.2.1 Calculator

The Hewlett-Packard 9825 calculator and its peripheral as configured for this application are shown in the Figure 3. The calculator is programmed in HPL which is a Hewlett-Packard version of multiple statement per line BASIC language. HPL executes faster than standard/basic. The calculator's work in conjunction with 24K words of 16-bit read/write memory and a number of read only memory (ROM) units. The ROMs required for this application are Advanced Programming ROMs. They are used as follows: FOR NEXT statements, String for character string manipulation, Matrix for array manipulation, General I/O and Extended I/O for buffered I/O, and HP-IB control. The calculator includes an alphanumeric keyboard and LED display for convenient operator interaction.

3.2.2 Printer

An HP9871A impact printer is the peripheral device utilized for displaying the computed spectral functions. This printer is a character-serial, impact printer capable of performing all normal typewriter and printer functions, plus plotting functions. All printer operations are controlled from the calculator through an HP-IB interface bus. This bus is the same as the IEEE standard 488 general instrumentation bus and is used to provide the system the capability for future expansion. All plotting commands and subroutines needed for this printer are included in a tape cartridge of general utility routines.

3.2.3 Analog-to-Digital Converter

A custom made analog-to-digital conversion module that takes the analog accelerometer data outputs from the magnetic tape reproduction unit was built into the system. This module changes the analog voltage to a parallel digital signal that the programmable calculator can read and operate on through its 16-bit duplex interface. This circuit consists of a high-speed sample-hold amplifier which is designed to acquire and hold up to a ± 10 -volt analog signal to an accuracy of $\pm 0.01\%$ of full scale range in:

- a. 5.0 microseconds for a 20-volt step
- b. 4.5 microseconds for a 10-volt step

The analog-to-digital converter (Fig. 4) uses successive approximations with a 12-bit resolution to output parallel digital data which is TTL compatible. This means that upon receipt of an external CONVERT command, the previous data sample is cleared from the output register and each bit is then successively compared against the amplitude of the input signal and is either held as a "0" or turned on as a "1" until all bits have been tried. The parallel data output is not available for transfer to the calculator's interface until the STATUS output changes from logic "1" to logic "0". The external CONVERT command is generated from a 100 kHz crystal oscillator and CMOS frequency divider chain illustrated in Figure 5. The final 2.5 kHz signal from this chain is fed to a monostable circuit which narrows the pulse width for the CONVERT command. The CONVERT command is gated with the valid interval signal from the tape search system so that the A to D converter outputs data only between the preset START and STOP times.

The STATUS output from the A/D converter is connected to the peripheral flag line on the 16-bit duplex interface. This "tells" the interface to read the converted digital value from the A/D output register to the interface's input register. The STATUS output from the A/D converter is also connected to the peripheral status line on the 16-bit

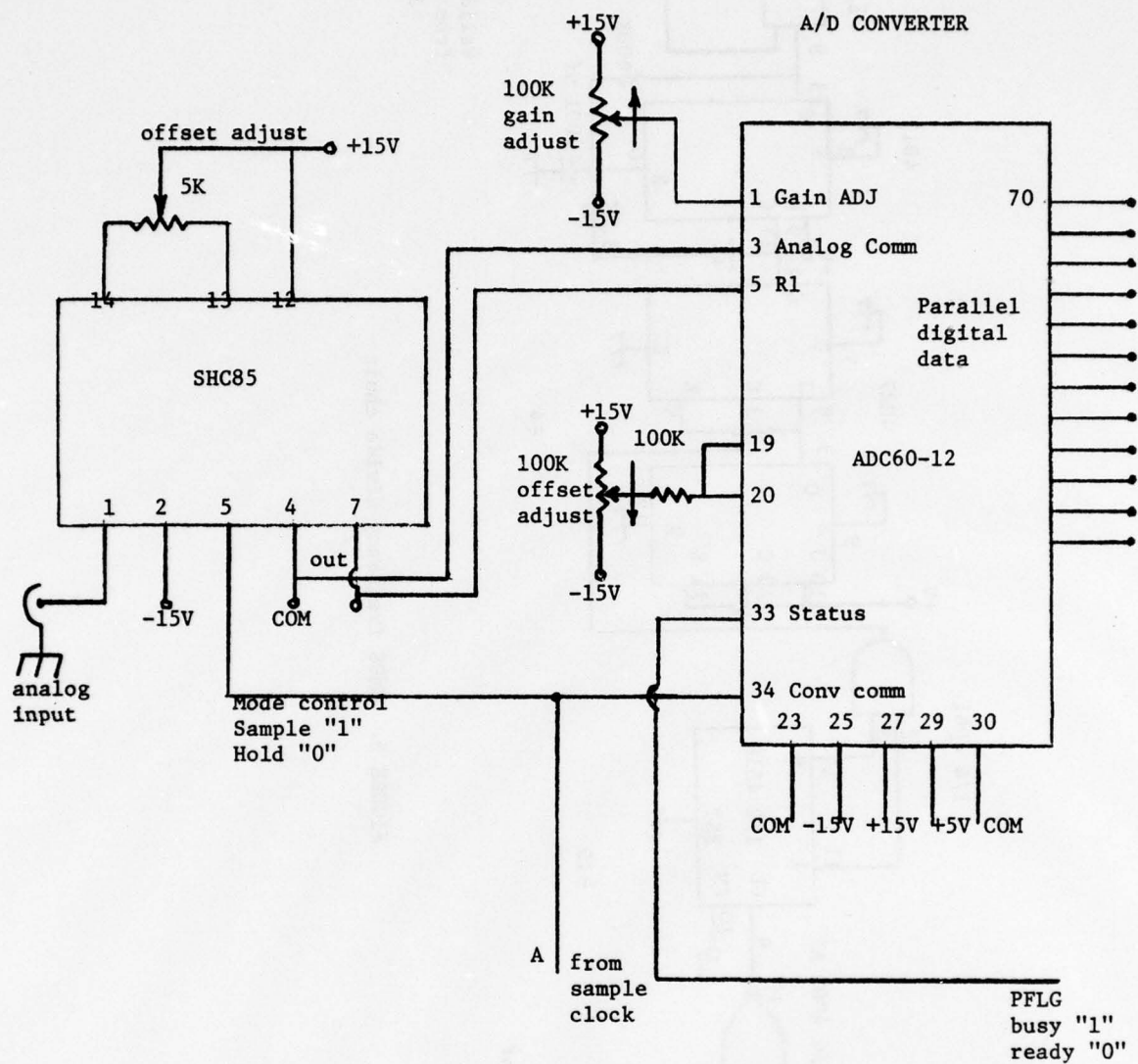


FIGURE 4. Sample-and-hold amplifier with analog-to-digital converter circuit

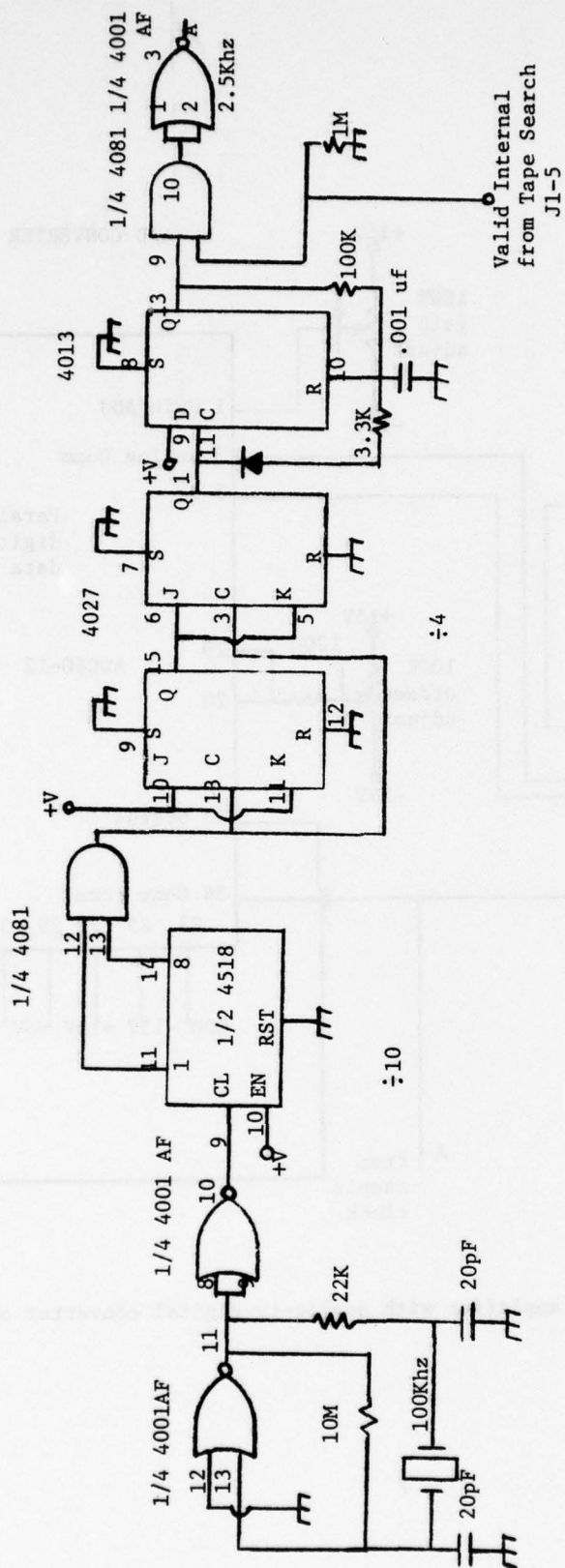


FIGURE 5. CMOS frequency divide chain

duplex interface. This is done so that the calculator can check this line under software control and read the value from interface's input register into its own memory buffer.

3.2.4 Tape Search Subsystem

A Tape Search and Control Unit is designed into the system to provide the necessary controls to automatically search the data tape to locate preselected START and STOP times. This device is used with the time code reader to accomplish this task. This START and STOP time is used later to control the length and location from the tape of the digitized accelerometer data. Panel lights provide front panel indication of the status of the tape transport as well as the entire system. Manual operation of the tape transport is also possible with the pushbuttons. Adjustments are provided to optimize tape travel during high-speed search. For example, the search operation is implemented based on time frame detection and on real-time durations. Since recording speeds vary with respect to search speeds, tape distances traveled also vary drastically.

Tape transports starting and stopping characteristics also vary. During search, it is necessary that the tape be stopped ahead of start time a sufficient distance so that detection of start can be made at a controlled speed, always in the same direction. It is undesirable to begin playback too far in front of START time since valuable time will be wasted before reaching START time. Likewise, if playback is initiated too close to START time, it could be missed due to transport start up times and time constant requirements. The tape search unit generates an output TTL comparable signal which is a logic "1" during the playback interval. This is used to gate the analog-to-digital conversion of the accelerometer data.

3.2.5 Time Code Recorder

The output from the time code reproduction amplifier in the magnetic tape playback unit is routed to a time code reader. The time code reader is designed to read the recorded time when played back from the magnetic tape.

The standard format is IRIG-B and includes BCD seconds, minutes and hours. By using the standard IRIG Format B, the reader is usable in conjunction with other systems or projects. The unit automatically decodes the serial input code and provides a front panel display and digital outputs. A synchronization mode, selectable from the front panel, provides noise rejection. This feature allows the selection of "zero," "one," "two," "four," "eight" or infinite time frames bypass if input errors are detected. This feature is very important when digital outputs are used or tape search operation is desired.

3.2.6 Recorder

The magnetic tape recorder/reproducer is capable of handling 14 channels of analog data at seven servo-controlled tape speeds with magnetic heads that are IRIG compatible. The methods of data handling include 13 channels of FM (+40% deviation) for accelerometer outputs, one channel of direct (analog) for recording and playing back time code data and one-half track for voice annunciation. The main recorder case is set up for recording only FM channels, recording and playing back voice channels, recording only time codes and the 28-volt dc input power supply for portable aircraft power operation.

In an operational environment this recorder unit and the time code generator are mounted on vibration shock mounts for easy installation and operation on-board the aircraft. The magnetic tape recorder is run at the 3-3/4 inch per second speed to get the required frequency response out to 1,000 Hz for the data analysis phase. This speed gives the recording system the capability for handling about 3 hours of continuous data per tape.

The data analysis phase of the system utilizes the same magnetic tape recorder unit from the acquisition phase except that the power supply can now be transformed to 117-volt ac operation. The outputs of each channel off the magnetic tape heads are routed to a portable auxiliary housing that has its own 117-volt ac power supply. This housing has all the reproduction electronics for the 13 FM channels and the one-time code channel built into it.

3.2.7 Time Code Generator

The time code generator is constructed in a standard one-half ATR configuration per Military Specification MS 91403 for its mounting on tray and shock mounts. This generator is capable of outputting IRIG-B standard time (hours, minutes and seconds) for correlating accelerometer data. This unit can be set up with any start time that may be useful to the test personnel and has a visual LED display on its front panel for ease of operation.

3.2.8 Accelerometers and Amplifiers

In the data acquisition phase of the vibration program, measurements of vibration environments will be accomplished by mounting accelerometers in aircraft or cargo locations of concern and recording the acceleration time histories on magnetic tape. The system initially uses two low mass triax accelerometers with their own internal preamplifiers to help eliminate cable noise and length dependence. These accelerometers have a battery power supply and external amplifier on each axis to provide an external X50 gain before inputting to the recorder unit. This external gain is needed to keep low acceleration values from being recorded

below the recorder's noise floor. The reason for this is that the recorder will record only down to about 0.3 volt in the FM mode. Any type accelerometer can be utilized with the system.

3.3 Software

The broad programming objectives were to reformat, by the use of a programmable calculator, the outputs from an analog to digital converter to a format which allows the project engineer a choice in the area of data parameter presentation.

The one digital technique which allows the system to operate is the use of an algorithm for the fast computation of Fourier transformations on a programmable calculator. The algorithm, usually referred to as a Fast Fourier Transform (FFT) procedure, has a great impact on vibrational data analysis because of its application to the calculation of spectral density functions.

Sampling for digital data analysis is usually performed at equally spaced intervals. The problem then is to determine an appropriate sampling interval h . Consider a continuous record which is sampled such that the time interval between sample values is h seconds. The sampling rate is then $1/h$ samples per second. However, a minimum of two samples per cycle are required to define a frequency component in the original data. Hence, the highest frequency which can be defined by sampling at a rate of $1/h$ samples per second is $1/2h$ Hz. Frequencies in the original data above $1/2h$ Hz will be folded back into the frequency range from 0 to $1/2h$ Hz, and will be confused with data in the lower range. So the highest frequency that can be used for a fixed sampling interval h is: $f_c = 1/2h$ which is called the Nyquist frequency or folding frequency. In this system there is a requirement for frequencies up to 1,000 Hz. So h has to be smaller than .0005 second. On the other hand, sampling at points much closer will yield highly redundant data and thus increase computer time. So h was chosen to be .0004 second for easy generation from a 100 kHz source. The tape recorder, because of the 3-1/2 inch per second speed, will cut off all frequency above 1.25 kHz and act as an antialiasing filter for frequencies above this Nyquist frequency. This means that the analog-to-digital converter is designed to sample the input analog voltage at 2.5 kHz.

The bipolar two's complement code from the 12-bit analog-to-digital converter is read into the calculator using a 16-bit parallel interface in the buffered I/O mode. A fast read/write buffer is used to simply collect the data as fast as possible without spending the time to convert data to the calculator's internal format. This work is done later by the input program after the data has been collected. This buffered I/O mode uses an 8,000-word buffer to read about three seconds of digitized data from the A to D converter.

The first job the software has is to format the input from the analog-to-digital 12-bit converter to a form that can be used by the Fast Fourier Transform (FFT) procedure program. The converter can handle a voltage swing of -10 volts to +10 volts on its analog input so its digital output encodes this bipolar voltage into a two's complement code. The two's complement code is mathematically achieved for negative numbers or voltages by complementing corresponding positive number and adding a "1" to the least significant bit. The resulting set is indeed an arithmetically consistent system and yet has only one zero state. This is illustrated in Figure 6.

When using the 16-bit interface in the fast read/write mode, it operates with negative-true logic so the input program must compensate for inverted logic.

The input program first checks the status line from the A to D to see if data are ready to be written into the 8K buffer. After this buffer is filled, the program takes 512 words from it and places these words into an array. Next the words in the array are inverted to compensate for inverted logic and the values checked to see if greater than 2047. If greater, the number is negative and 4096 is subtracted from it. This changes the number range to -2048 to +2047.

Next, the numbers are divided by 204.7, which changes the number range again to the new range of -10 to +10. This range corresponds to the voltages seen on the analog input to the A/D converter. Before this has happened, the calculator has asked which accelerometer was used on this channel and places the sensitivity factor (volts per g acceleration) into variable G. This value is used to convert voltages from the accelerometers to acceleration to be used by the Fast Fourier Transform program.

The input program stores this corrected 512-word array onto tape and takes another 512 words from the buffer for conversion. After the program has run through the entire buffer, there are sixteen 512-word files on tape for the FFT program to operate on.

3.3.1 FFT Procedural Steps

The following steps were used to compute power spectra estimates via FFT procedures. Assume that the sample size for the data sequence X_n is initially of arbitrary size N which in our case is 512.

a. Truncate the data sequence or add zeros so that $N=2^P$ since Fast Fourier Transforms operate more efficiently in this matter if N is a power of two.

Ten volts	0111	1111	1111 = 2047	full positive
	0111	1111	1110 = 2046	-1 LSB
Five volts	0100	0000	0000 = 1024	+half full scale
			0001 = 1	+1 LSB
Zero volts	0000	0000	0000 = 0	Zero
			1111 = 4095	-1 LSB
Negative five volts	1100	0000	0000 = 3072	-half full scale
			0001 = 2049	-FS+ LSB
Negative ten volts	1000	0000	0000 = 2048	-FS

Figure 6. Two's complement 12-bit code

b. Taper the resulting sequence using the cosine taper data window of Figure 7 to take into account the effects of leakage. Leakage means that components of $f(t)$ not periodic over the interval NT appear to leak out into portions of the spectrum adjacent to the correct spectral value. This is caused by the sharp corners of the rectangular window $w(t)$ of duration NT caused by the digitizing of a discrete number of samples. The method for reducing this effect would be simply to round off the sharp corners of $w(t)$ by using the cosine taper and correcting for this window after doing the FFT.

c. Compute X_k where
$$X_k = \frac{X(f_k, T)}{h} = \sum_{n=0}^{n=N-1} x_n \exp \left[-j \frac{2\pi kn}{N} \right]$$

for $k=0, 1, N-1$ where X_k are the Fourier components calculated from the FFT procedure using the adjusted data sequence from the last step.

d. Compute the power spectrum estimate \hat{G}_k where $\hat{G}_k = \hat{G}_x(f_k) = \frac{2h}{N} |X_k|^2$ where the frequency of each estimate is $f_k = \frac{k}{T} = \frac{k}{Nh}$ and $k=0, 1,$

... $N-1$, $N-1$ is the number of the estimate. Note that the arrays are numbered 1 to N , not 0 to $N-1$ in the actual software.

e. Adjust these estimates by a scale factor because of the tapering used in step 2 by replacing \hat{G}_k by $(1/0.875) \hat{G}_k$ if the cosine tapering window of Figure 7 is used.

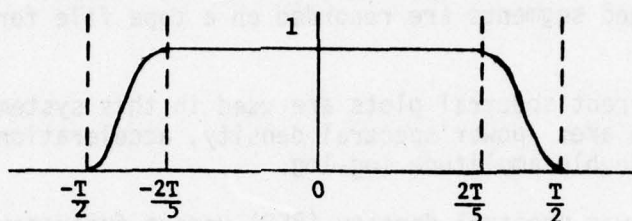
This procedure is workable for only a data sequence of length N . The N is the number of points used by the FFT algorithm and is limited in this system to 512 by the memory size of the calculator for storing arrays.

The method used to get around this is to divide the time domain, t , into a number of segments of equal length N , compute a discrete spectrum for each segment using the FFT algorithm and then use the scaled average of the squared values of these estimates for the power spectral estimate. In computing the discrete spectrum of each segment a cosine tapering data window was impressed over each segment in order to smooth the data sequence for reducing leakage as described before. The squared X_k Fourier components for each segment are averaged in program and the final spectral estimate put on tape for use by the plotting programs.

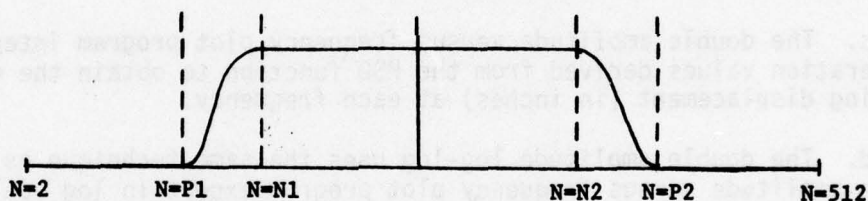
In this method, the number M of frequency bands becomes the number of independent FFT values or one-half the number of samples in a segment. The number of segments K was chosen to be 16 because this is the maximum number of segments the calculator's memory and tape system can easily handle. The expression for the power spectral estimate now becomes:

Assume that C_T is defined by continuous function:

$$\begin{aligned}
 C_T(t) &= \cos^2 \frac{5\pi t}{T} & -\frac{T}{2} \leq t \leq -\frac{2T}{5} \\
 &= 1 & -\frac{2T}{5} \leq t \leq \frac{2T}{5} \\
 &= \cos^2 \frac{5\pi t}{T} & \frac{2T}{5} \leq t \leq \frac{T}{2} \\
 &= 0 & \text{Otherwise}
 \end{aligned}$$



Redefine as discrete function:



Where $N1 = [(P2-P1)/10]+P1$ and $N2 = P2 - [(P2-P1)/10]$

$$\begin{aligned}
 C(N) &= \sin^2 \frac{5\pi(N-P1)}{(P2-P1)} & P1 \leq N \leq N1 \\
 &= 1 & N1 \leq N \leq N2 \\
 &= \sin^2 \frac{5\pi(N-P1)}{(P2-P1)} & N2 \leq N \leq P2 \\
 &= 0 & \text{Otherwise}
 \end{aligned}$$

FIGURE 7. Cosine taper data window

$$\hat{G}_k = \frac{T}{2MKW} \sum_{k=1}^K |x_k|^2; K = 0.1, \dots, N-1$$

where T = sampling interval in seconds

M = no. frequency values from 0 to 1/2 Thz

K = no. segments

W = scale factor for adjusting tapering

Also note that it was best to use disjoint, nonoverlapping segments because the overall record length of $f(t)$ is 8,000 points which is the maximum size buffer the calculator's memory can handle. The output from these 16 averaged segments are recorded on a tape file for use by plotting routines.

Four different spectral plots are used in this system to analyze the data; these are: power spectral density, acceleration, double amplitude and double amplitude log-log.

a. The power spectral density (PSD) versus frequency program performs no additional processing on the data contained in the FFT output file, it only automates the job of plotting.

b. The acceleration versus frequency program converts PSD data to units of g rms and plots that data.

c. The double amplitude versus frequency plot program integrates acceleration values derived from the PSD function to obtain the corresponding displacement (in inches) at each frequency.

d. The double amplitude log-log uses the same technique as the double amplitude versus frequency plot program except in log scale on both axis and with a MIL-STD-810C vibration curve superimposed on it. The curve selected is curve AW for equipment category G. This is the curve which is used for test items that are air transported by the Air Delivery Engineering Branch. This gives the project engineer a quick way of checking if all the data points in this segment of time data falls below this curve and passes the military standard it is being tested against.

4.0 RESULTS

The Airborne Recording System has successfully utilized the versatility and data processing capability of a modern programmable calculator for vibration analysis. This approach makes possible the addition of other analog or digital transducers for other requirements without the procurement of different analysis instrumentation.

The use of the Fast Fourier Transfer program in a calculator this memory size has limited analysis to 3.2 seconds of data at one time. This amounts to about 8,000 data points in 6 minutes of calculator's execution time. So the first step that should be done is an analog strip recording of time history from the recorder to find the times of interesting events. Then these times should be used for detailed analysis on the calculator.

The Airborne Recording System was first used during the air transportability testing of the Patriot missile which utilized a CH-47 Chinook helicopter. The acquired spectral vibrational data is briefly summarized in the plots illustrated in Figures 8 through 11.

The Power Spectral Density (PSD) function is an indication of the amount of vibrational energy at a particular frequency at a particular location of the test item and is depicted in Figure 8. The test item has been subjected to random vibrations along each of three mutually exclusive axis and measured by triaxial accelerometers, placed at predetermined locations. The Power Spectral Density function of any test item, under any flight environment, shall not deviate predetermined specifications by more than a predetermined percentage as specified in MIL-STD-810C. In addition, the PSD function provides the various resonance peaks that the test item is being subjected to aboard the aircraft. The PSD function is the most important parameter in vibrational analysis of air transportability testing, since most other important and required parameters can be derived from the PSD function.

The Acceleration G RMS function, plotted in Figure 9, is used to determine resonance response peaks during a test flight in air transportability testing. The frequencies at which significant resonance response peaks occur are identified for each triaxial accelerometer mounted on the test item. This information is then utilized for resonance dwell tests to determine if a test item can withstand maximum dynamic stress (endurance tests) as defined in MIL-STD-810C.

The Double Amplitude function, illustrated in Figure 10 is required to determine the maximum movement of the test item at low frequencies during any air transportability test. This measurement is required for tie-down/stress design considerations.

The Double Amplitude LOG function, plotted in Figure 11, is superimposed with and compared to a MIL-STD-810C vibration analysis curve for the air transportability equipment category. This comparison determines the number of data points and their frequency which fall within the MIL-STD-810C curve and/or to determine, for those data points outside the curve, how close they are to the worst case curve.

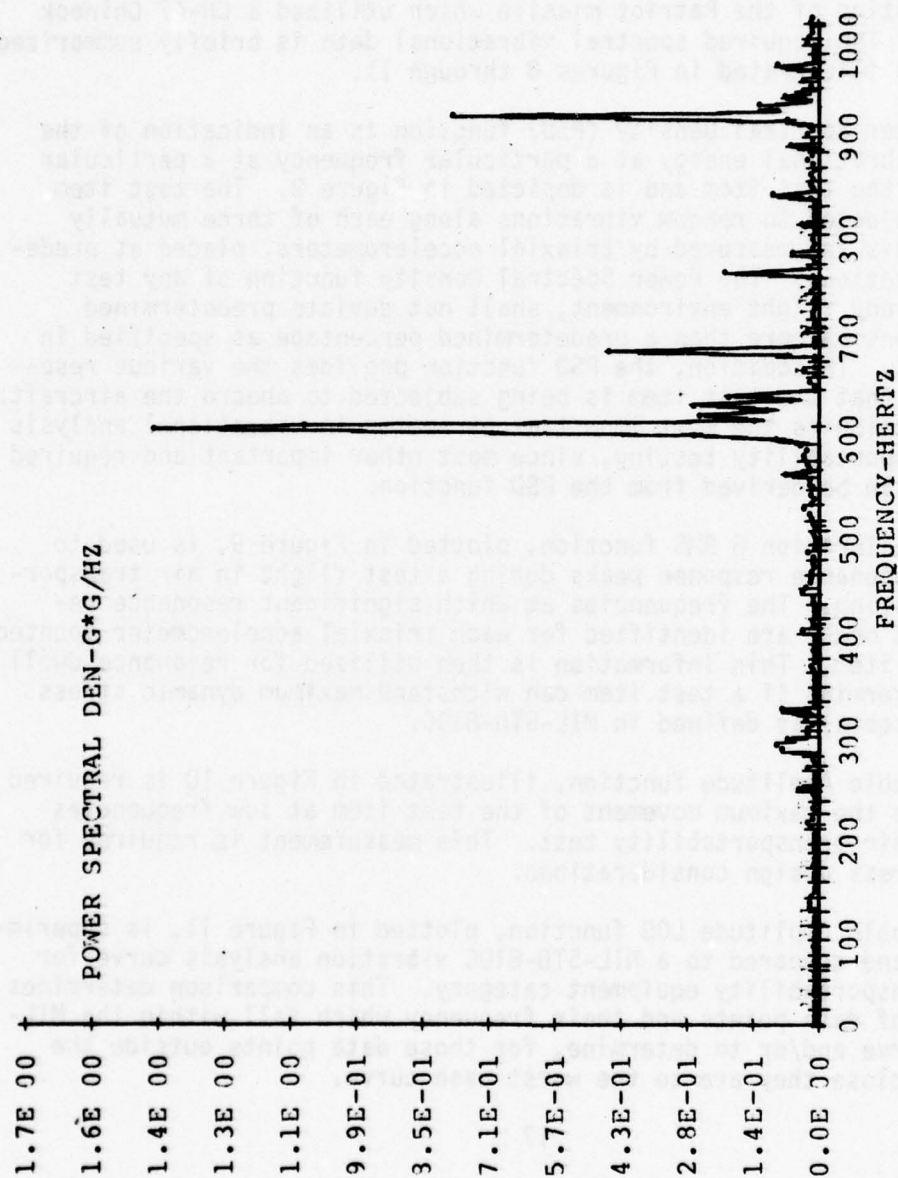


Figure 8.

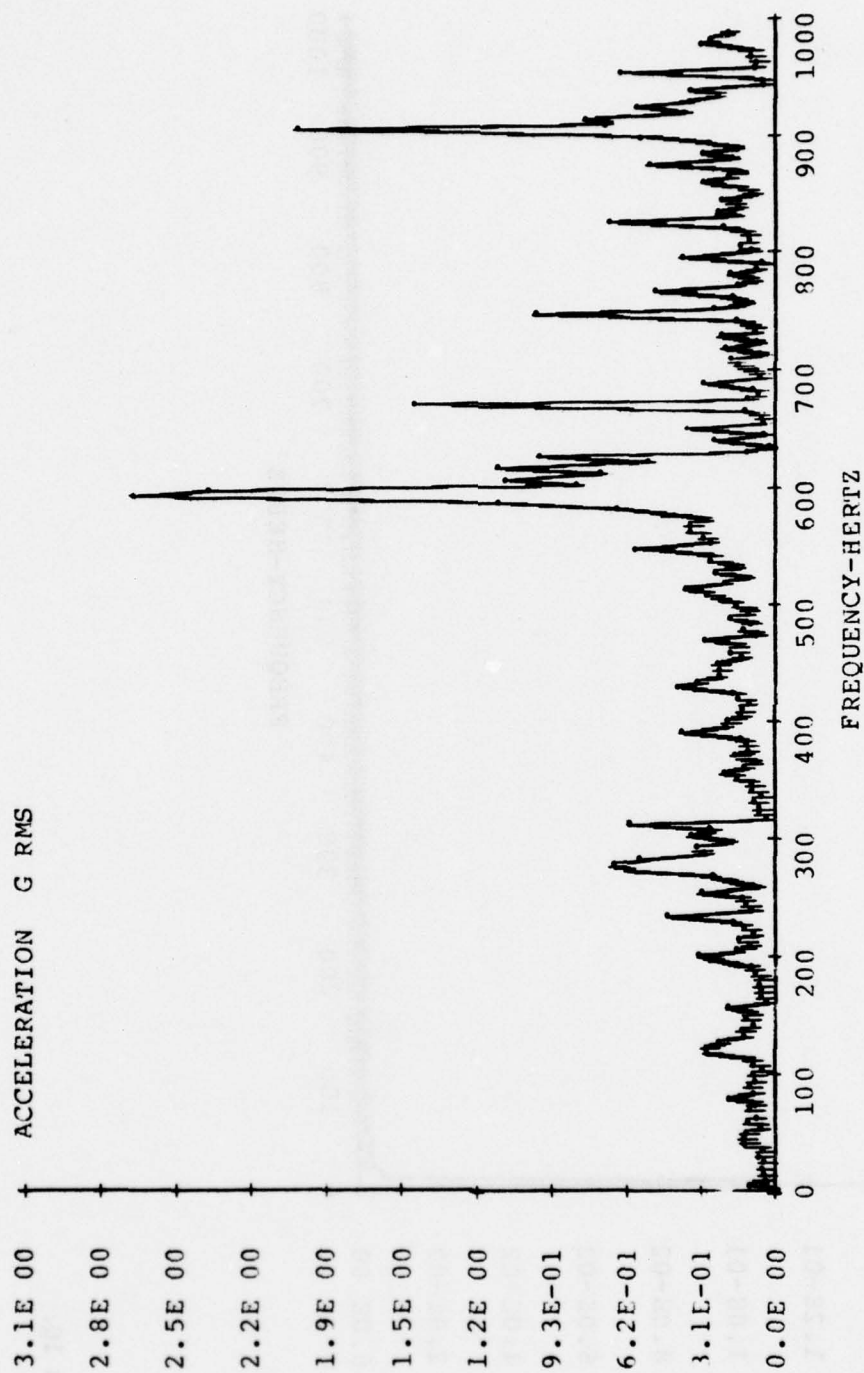


Figure 9.

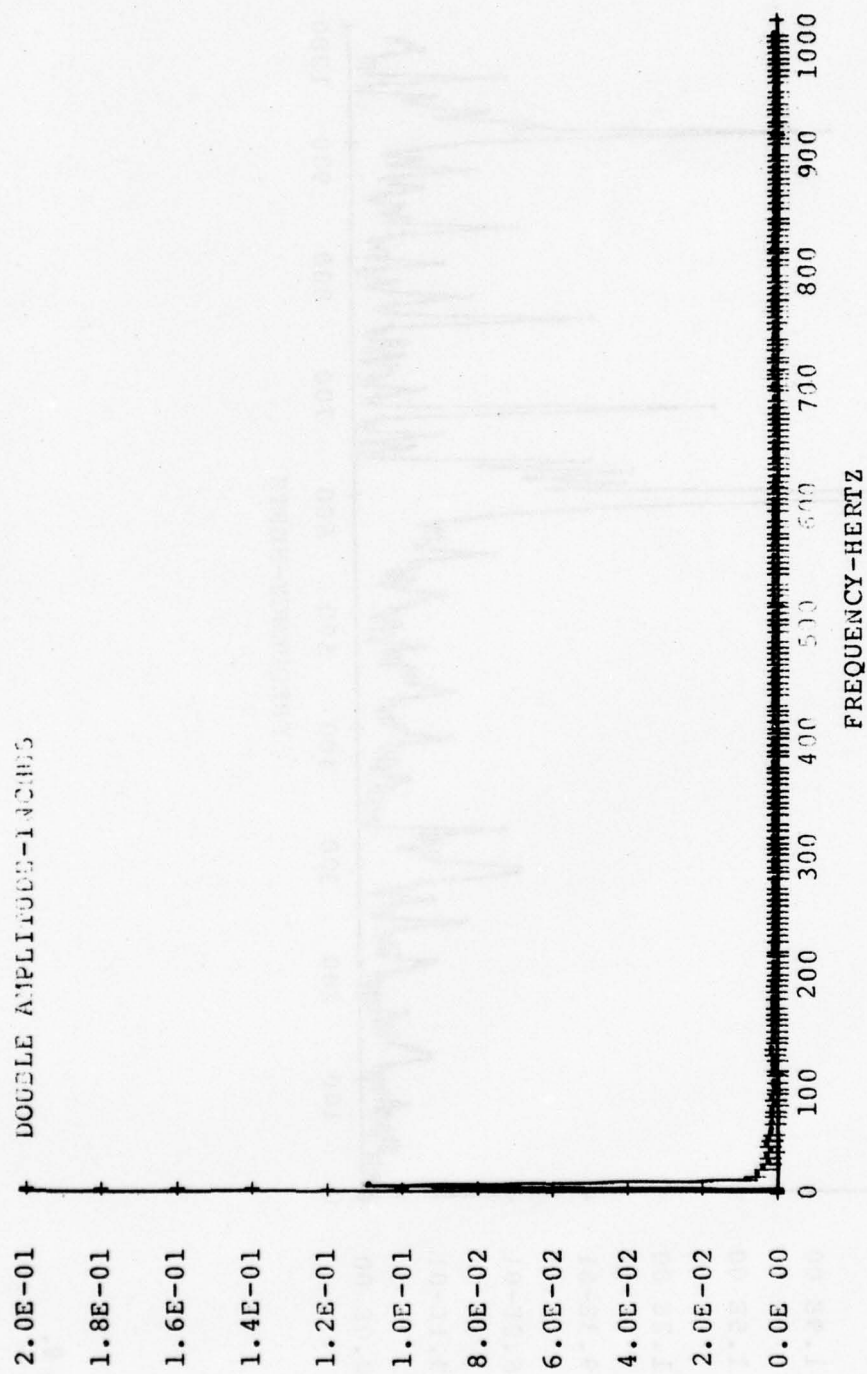
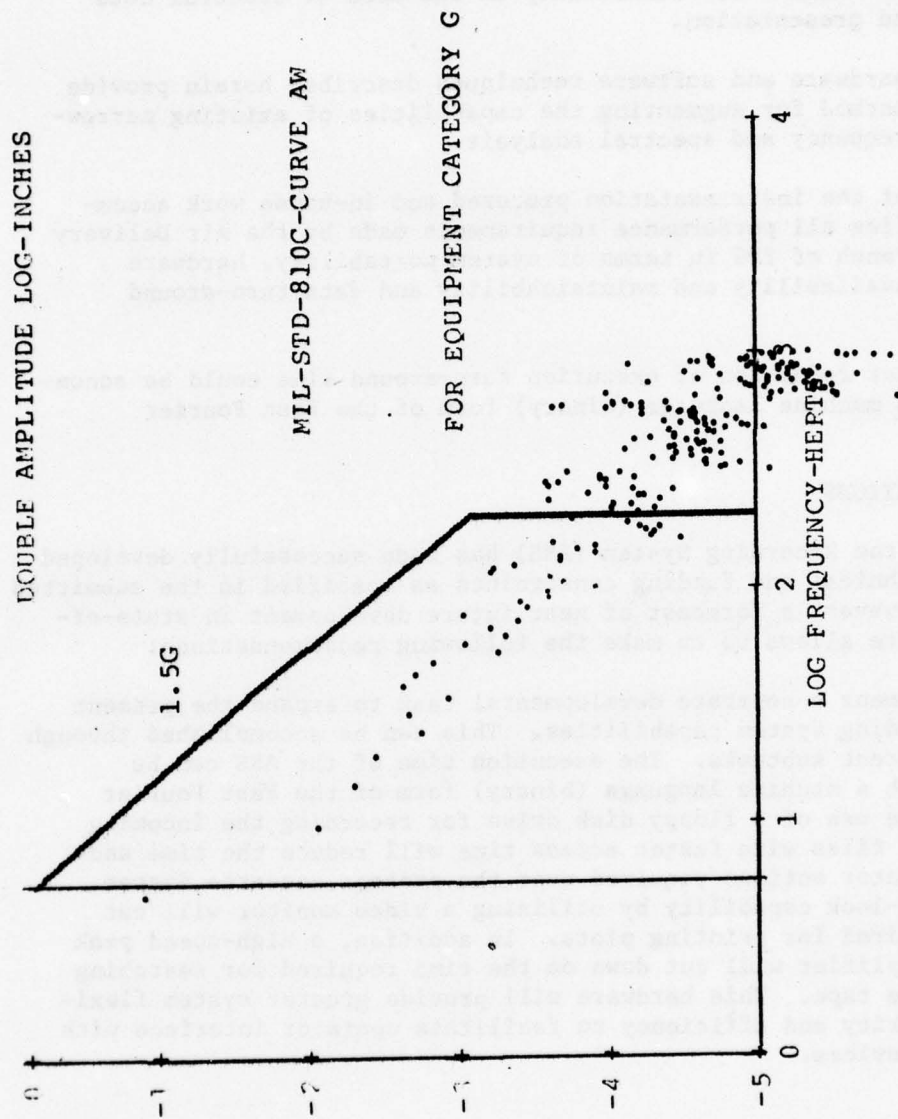


Figure 10.



5.0 CONCLUSIONS

The Airborne Recording System (ARS) development project has been successfully completed and the following conclusions arise:

a. The development of the ARS instrumentation system provides the project engineer with a new flexibility in the area of spectral data computation and presentation.

b. The hardware and software techniques described herein provide an alternate method for augmenting the capabilities of existing narrow-band, swept frequency and spectral analysis.

c. All of the instrumentation procured and in-house work accomplished satisfies all performance requirements made by the Air Delivery Engineering Branch of YPG in terms of system portability, hardware reliability, availability and maintainability and data turn-around times.

d. Further reduction of execution turn-around time could be accomplished with a machine language (binary) form of the Fast Fourier algorithm.

6.0 RECOMMENDATIONS

The Airborne Recording System (ARS) has been successfully developed within the technical and funding constraints as specified in the submitted proposals. However, a forecast of near future development in state-of-the-art hardware allows us to make the following recommendations:

a. Implement a separate developmental task to expand the present Airborne Recording System capabilities. This can be accomplished through several concurrent subtasks. The execution time of the ARS can be speeded up with a machine language (binary) form of the Fast Fourier algorithm. The use of a floppy disk drive for recording the incoming data in larger files with faster access time will reduce the time and number of operator actions required over the present cassette system. Adding a quick-look capability by utilizing a video monitor will cut down time required for printing plots. In addition, a high-speed peak sample-hold amplifier will cut down on the time required for searching the data on the tape. This hardware will provide greater system flexibility, modularity and efficiency to facilitate operator interface with input/output devices.

b. Modify the present ARS to provide a miniaturized version of the airborne components of the ARS. This task will provide a one-man portable ARS. This can be accomplished with a recorder/reproduce subsystem that will become available off-the-shelf in the near future. The record/reproduce subsystem size and weight will be reduced by a factor of 4. Furthermore, the recent development of FFT modules and I/O controller circuitry will allow software development in machine language for permanent storage on read-only-memories for the Data Analysis subsystem of the ARS.

SECTION II. APPENDICES

APPENDIX A - ARS OPERATING PROCEDURES

1.0 RECORDER/REPRODUCER SYSTEM

1.1 General Preoperation Procedures

- a. Set the CALIBRATE switch (left interface panel) to OFF.
- b. Set the TAPE/TONE switch (right interface panel) to TONE for tone wheel signal reference of the capstan servo which should serve most purposes.
- c. Make sure the tape SPEED switch is in the 3-3/4 in./sec position.
- d. Make sure SPEED SELECTION JACKS for equalization SPEED on left side has a jumper pin in the jack corresponding to 3-3/4.
- e. Make sure SPEED SELECTION JACKS for equalization SPEED B on right side has a jumper pin in the jack corresponding to 15.
- f. Mount the tape reels by raising the locking latch, setting the reel over the hub and snapping the locking latch down.
- g. Thread the tape past the head assemblies and around the capstan rollers as illustrated on the bottom of the head cover when it is flipped up.

1.2 Record Operation Procedures

- a. After checking for installation of 28-volt dc power supply, insert record transport unit into its mounting tray. See recorder manual for instructions in the change of the power supply procedures.
- b. Connect coax cable from each accelerometer to an input BNC connector on interface panels and label.
- c. Connect coax cable from time code generator to channel 8 input BNC connector on interface panel.
- d. Connect power cable to recorder power connector and other end to 28-volt dc female connector next to recorder tray.
- e. Connect headphone and mike to VA input, VA output and voice recorder act coax BNC connectors.
- f. Connect power cable from the time code generator to the other 28-volt dc female connector next to recorder tray.

g. Connect power cable from the two female connectors next to recorder tray to aircraft power, observing proper polarization of (-) and (+).

h. Set POWER switch on time code generator to the ON position.

i. On the time code generator the nine-digit display shows the accumulated time count. The DECADE switch selects the counter decade (units-of-seconds, units-of-minutes, etc) to be preset; position 1 selects the units-of-seconds decade and so on from the least significant digit. The TIME switch selects the digit to be entered into the selected decade. The SET push button is pressed to enter the selected digit. The START push button is used to manually start the clock, the STOP push button is used to manually stop the clock. The RESET push button is used to manually reset the time counters.

j. Turn accelerometers amplifier boxes ON and gain switches to X50.

k. To start the recording of data, set POWER switch on recorder to ON. Press the DRIVE FORWARD and the RECORD push buttons at the same time.

NOTE: If tape does not begin to move, check that tension of the tape has moved the tension arms away from their extreme released position.

1.3 Playback Operation Procedures

a. Check for installation of 110-volt ac power supply. See recorder manual for instructions on how to change the power supplies.

b. Connect the coaxial cables as required for channels to be reproduced; the cable sequence is from the output of the Model 5600 recorder to the input of the auxiliary housing and from the auxiliary housing output to the external data processing equipment.

c. Connect the power cables from the auxiliary housing and recorder to facility power.

d. Connect the auxiliary cable from the AUX connector on the Model 5600 recorder to the AUX connector on the auxiliary housing.

e. Set POWER switch on both units to ON.

f. See tape search operation procedures for rest of playback procedures.

2.0 TAPE SEARCH SYSTEM

2.1 Turn On Procedure

a. Connect the interconnect cable from J3 on the Model 9240 tape search and control unit to the Model 9200A time code generator/translator J4 connector.

b. Connect tape search units to the J2 connector tape transport remote operation connector.

c. Place the standard 1 kHz modulated IRIG B code signal from recorder/reproducer time code channel output BNC connector to BNC connector J1 on Model 9200A time code generator/translator.

d. Apply 115-volt ac power to J6 connector on Model 9200A time code generator/translator.

e. Rotate the Mode switch to the TRANS position on time code generator/translator.

f. Place the FWD/REV switch to the FWD position on time code generator/translator.

g. Place the INPUT+/- toggle in the normal (+) position on the time code generator/translator.

h. Insure that the FILTER switch is in the IN position on the time code generator/translator.

i. Apply 115-volt ac power to J6 connector on the tape search and control unit.

j. The Model 9240 tape search and control unit and the Model 9200A time code generator/translator are powered when the PWR switch is placed to the ON position on both units.

k. Allow approximately one minute after turn-on for AGC to settle; the time code generator/translator will automatically synchronize to the input time code.

2.2 Manual Search Control on Tape Search System

a. Set operational mode switch to MANUAL.

b. Between each manual command, a manual stop command must be initiated by pressing STOP on the tape search and control unit.

- c. STOP: Press STOP to stop transport.
- d. FWD: Press FWD to place transport in FWD mode.
- e. FAST: Press FAST pressing either FWD or REV to place transport in the FAST mode.

2.3 Search to Start

The tape search unit provides for time increment selection from the front panel by means of thumbwheel switches. Thumbwheel switches (for hours, minutes, seconds) are provided for START and STOP times. Five operational modes are selectable from front panel.

- a. Set operational mode switch to the SEARCH/START position.
- b. Preset the START time thumbwheel switches to the desired times.
- c. Press START, the transport will stop just below the present start time. Once stopped, the system now awaits further instructions.

2.4 Single Cycle Mode

The tape is moved ahead of start time and is stopped. "Playback" is automatically activated and transport is placed into the forward mode. The transport is stopped at the detection of STOP time and is ready for a new operation. This is the normal mode for reading data off of tape into the calculator.

- a. Set operational mode switch to the SINGLE CYCLE position.
- b. Preset the desired START time on the START TIME thumbwheel switches located on the front of the tape search and control unit.
- c. Preset the desired STOP time on the STOP TIME thumbwheel switches located on the front of the tape search and control unit.
- d. NOTE: Four seconds difference is required between START and STOP time to fill calculator memory.

2.5 Recycle Mode

This mode provides for repeated single cycle operation. The procedure is the same as single cycle except that the operational mode switch is in the RECYCLE position. The "STOP" pushbutton must be activated to stop "RECYCLE" operation.

3.0 CALCULATOR SYSTEM

3.1 Turn ON Procedure

- a. Connect the power line into ac power outlets for printer and calculator.
- b. Switch the calculator ON using the switch on the right-hand side of the calculator.
- c. Insert the tape cartridge so that the label on the cartridge faces the back of the calculator.
- d. Push system command key REWIND to rewind the tape cartridge to its beginning.
- e. Connect the HIB-bus interface cable to the I/O connector at the rear of the printer, and to the calculator rear peripheral connector.
- f. Switch the OFF/ON switch located on the right front of the printer to the ON position.
- g. Connect the 16-bit 98032A interface cable from the digitizer to one of the calculator rear peripheral connectors.
- h. Connect the power cord from the digitizer into an ac power outlet.

3.2 Calculator Operation

- a. Type idf 0 and press execute key; this loads the input program into the calculator's memory.
- b. Connect coax cable from the desired channel of the recorder/reproducer to the digitizer's BNC connector.
- c. Set the tape search system for desired START and STOP times. Note that it must be four seconds difference.
- d. Push RUN on calculator keyboard.
- e. Start tape search system operation as described before.
- f. The calculator's display will ask what accelerometer number was utilized on this channel. Type in the number from the keyboard and push the CONTINUE key.

g. The calculator's display will ask the gain used with that accelerometer. "1" means times 1 and "2" means times 10. Type in the number from the keyboard and push the CONTINUE key.

h. When the "lazy T" shows on the display the input program is done.

i. Push the ERASE, the A and the EXECUTE keys sequentially on the calculator's keyboard. This erases the entire calculator memory.

j. Type ldf 1 and press EXECUTE key; this loads the FFT program into the calculator's memory.

k. Push RUN key on the calculator's keyboard to start the program.

l. When the "lazy T" shows on the display, the FFT program is done.

m. Push the ERASE, the A and the EXECUTE keys sequentially on the calculator's keyboard. This again erases the entire calculator memory.

n. Type ldf N where N=19 for power spectral density plot, N=20 for acceleration plot, N=21 for double amplitude plot and N=22 for double amplitude log plot. Press EXECUTE key for loading desired plot program into the calculator's memory.

o. Push RUN key on the calculator's keyboard to start the plotting program.

p. When plotting is done the calculator's display will ask if another copy of the plot is desired. Type "1" for YES and "0" for NO and press the CONTINUE key.

q. When the "lazy T" shows on the display the plotting program is done.

r. Push the ERASE, the A and the EXECUTE keys sequentially on the calculator's keyboard. This again erases the entire calculator memory.

s. Repeat steps n. through r. for all different plots desired for that data segment.

t. Repeat all operation steps for each new data channel or segment being analyzed.

u. Check for paper in printer. To load paper, first move paper release lever back, place the paper behind the platen with the left edge of paper at the desired position. Lift the paper bail up then turn the platen knob clockwise to feed the paper around the platen. Push the paper bail down and ensure that the paper travels behind the bail. To remove or reposition the paper in the printer, move the paper release lever forward. With the lever forward the paper is free to move. When the paper is properly positioned (horizontally and verically), move the lever back for details, consult the printer manual.

APPENDIX B. PROGRAM LISTINGS

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PERMIT FULLY LEGIBLE TRANSCRIPTION
INPUT DATA PROGRAM

```
0: dim X[512],A[6]
1: buf "hold",8192,2
2: iosl3→L;if L=0;jmp 0
3: tfr 13,"hold",8192
4: rds("hold")→K;if K=-1;jmp 0
5: .00975→A[1]
6: .00994→A[2]
7: .00988→A[3]
8: .01015→A[4]
9: .0098→A[5]
10: .01078→A[6]
11: dsp "ENTER ACC. TRANSDUCER NUMBER";wait 1000
12: ent R
13: A[R]→G
14: dsp "ENTER 1 FOR 1X SENSITIVITY OR 2 FOR 10X";wait 1000
15: ent Q
16: if Q=1;gto +3
17: 10→M
18: gto +2
19: 1→I
20: M→G→G
21: for J=1 to 16
22: for I=1 to 512
23: rdb("hold")→X[I]
24: -X[I]→X[I]
25: gto +1;if X[I]<2048;gto +2
26: X[I]-4096→X[I]
27: next I
28: for I=1 to 512
29: X[I]/(G*204.7)→X[I]
30: next I
31: 1→A
32: 512→B
33: (B-A)/10→A→C
34: B-(B-A)/10→E
35: for I=A to B
36: gto +1;if I≤C;gto +4
37: gto +1;if I>=E;gto +3
38: wait 1
39: gto +3
40: rad;sin(5*π*(I-A)/(B-A))→F
41: F^2*X[I]→X[I]
42: next I
43: rcf J+1,X[*]
44: next J
45: end
```


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FAST FOURIER TRANSFORM PROGRAM

```
0: 512→N
1: dim X[512],Y[512],C[129],D[2,256]
2: for A=1 to 16
3: ldf A+1,X[*]
4: N/4→G;G+1→H
5: H+1→J;G+J→K
6: int(log(N)/log(2)+.5)→L
7: 2*π/N→M
8: for O=1 to H
9: cos((O-1)*M)→C[O]
10: next O
11: for O=1 to L
12: 2^(L-O)→P
13: 2*P→Q;N/Q→R
14: for S=1 to P
15: (S-1)*R+1→T
16: if T≤H;gto +4
17: -C[K-T]→M
18: -C[T-G]→X
19: gto +3
20: C[T]→M
21: -C[J-T]→X
22: for U=0 to N-Q by Q
23: U+S→V
24: V+P→Y
25: X[V]-X[Y]→Z
26: Y[V]-Y[Y]→D
27: X[V]+X[Y]→X[V]
28: Y[V]+Y[Y]→Y[V]
29: M*Z-X*D→X[Y]
30: M*D+X*Z→Y[Y]
31: next U
32: next S
33: next O
34: L+1→O
35: for P=1 to 8
36: 1→C[P]
37: if P>L;gto +2
38: 2^(O-P)→C[P]
39: next P
```

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```
40: 1→D
41: for O=1 to C[3]
42: for P=O to C[7] by C[8]
43: for Q=P to C[6] by C[7]
44: for R=Q to C[5] by C[6]
45: for S=R to C[4] by C[5]
46: for T=S to C[3] by C[4]
47: for U=T to C[2] by C[3]
48: for V=U to C[1] by C[2]
49: if D>V;gto +7
50: X[D]→M
51: X[V]→X[D]
52: M→X[V]
53: Y[D]→M
54: Y[V]→Y[D]
55: M→Y[V]
56: D+1→D
57: next V
58: next U
59: next T
60: next S
61: next R
62: next Q
63: next P
64: next O
65: 0→B
66: .0004→W
67: for I=1 to 256
68:  $X[I]^2 + Y[I]^2 \rightarrow X[I]$ 
69:  $W * X[I] / (N * .875) + D[1, I] \rightarrow D[1, I]$ 
70: next I
71: ina Y
72: prt A
73: next A
74: for I=1 to 256
75:  $I / (N * W) + D[2, I]$ 
76:  $D[1, I] / 16 + D[1, I]$ 
77: next I
78: rcf 18, D[*]
79: end
```

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PSD PLOT PROGRAM

```
0: dim D[2,256]
1: 701→r0
2: 0→C;1000→E;0→B;ldf 18,D[*]
3: for I=1 to 206
4: if D[1,I]<B;gto +2
5: D[1,I]→B
6: next I
7: 100→F;1000→D
8: cll 'form'(14,11,11)
9: cll 'psiz'(8,9,1,2)
10: cll 'scl'(C-.2*D,E,-.1*B,1.1*B)
11: cll 'xaxis'(0,F,C,E)
12: cll 'yaxis'(C,.1*B,0,1.1B)
13: for G=C to E by F
14: cll 'move'(G,0)
15: cll 'space'(-3)
16: cll 'skip'(1)
17: if G>E;gto +2
18: fmt 2,f4.0
19: wrt 701.2,G
20: next G
21: cll 'move'(.4*D,-.05*B)
22: wrt 701,"FREQUENCY-HERTZ"
23: for G=0 to 1.2*B by .1*B
24: cll 'move'(C-.16*D,G)
25: fmt 4,e8.1
26: wrt 701.4,G
27: next G
28: cll 'move'(.05*D,1.1*B)
29: wrt 701,"POWER SPECTRAL DEN-G*G/HZ"
30: cll 'move'(C,0)
31: for J=1 to 256
32: if D[2,J]>=C;gto +2
33: gto +3
34: cll 'plot'(D[2,J],D[1,J])
35: if D[2,J]>=E;gto +2
36: next J
37: dsp "DO YOU WANT ANOTHER PLOT"
38: wait 500
39: ent W
40: wtb r0,13
41: if W=1;gto 10
42: end
```


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```
43: "move":
44: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
45: ret
46: "plt":
47: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
48: if p3=0;46→p3
49: if p3=46;wtb r0,27,82,0,0,0,6
50: wtb r0,p3;wtb r0,8
51: if p3=46;wtb r0,27,82,0,0,63,-6
52: ret
53: "fplt":
54: wtb r0,27,97,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
55: if p3=0;46→p3
56: if p3=46;wtb r0,27,82,0,0,0,6
57: wtb r0,p3;wtb r0,8
58: if p3=46;wtb r0,27,82,0,0,63,-6
59: ret
60: "psiz":
61: p1→H;p2→W
62: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
63: ret
64: "scl":
65: 120W/(p2-p1)→U
66: 96H/(p4-p3)→V
67: p1→X;p3→Y
68: ret
69: "xaxis":
70: wtb r0,27,46,95,0,5,9
71: if p3=0 and p4=0;X→p3;X+120W/U→p4
72: if p2=0;p4-p3→p2
73: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64)
,int((p1-Y)V)
74: p3→p5;wtb r0,43;wtb r0,8
75: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p
5+p2+p5)→p4
76: ret
```

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```
77: "yaxis":
78: wtb r0,27,46,124,0,3,0
79: if p3=0 and p4=0;Y→p3;Y+96H/V→p4
80: if p2=0;p4-p3→p2
81: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64)
,int((p3-Y)V)
82: p3→p5;wtb r0,43;wtb r0,3
83: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (p
5+p2→p5)>=p4
84: ret
85: "space":
86: if p1<0;gto +2
87: wtb r0,32;jmp 2((p1-1→p1)=0)
88: wtb r0,8;jmp (p1+1→p1)=0
89: ret
90: "skip":
91: if p1<0;gto +2
92: wtb r0,10;jmp 2((p1-1→p1)=0)
93: wtb r0,27,10;jmp (p1+1→p1)=0
94: ret
95: "form":
96: wtb r0,27,77
97: wtb r0,27,84
98: if p1=0;13.2→p1;11→p2→p3
99: wtb r0,27,87,int(120*p1/64),120*p1
100: wtb r0,27,76,int(96*p2/64),96*p2
101: wtb r0,27,70,int(96*p3/64),96*p3
102: ret
```

ACCELERATION PLOT PROGRAM

```

0: dim D[2,256]
1: 0→B;ldf 18,D[*]
2: 4.88→R
3: for I=1 to 256
4: √(R*D[1,I])→L
5: if L<B;gto +2
6: L→B
7: next I
8: prt B
9: 701→r0
10: 0→C;1000→E;1000→D;100→F
11: cll 'form'(14,11,11)
12: cll 'psiz'(8,9,1,2)
13: cll 'scl'(C-.2*D,E,-.1*B,1.05*B)
14: cll 'xaxis'(0,F,C,E)
15: cll 'yaxis'(C,.1*B,0,1B)
16: for G=C to E by F
17: cll 'move'(G,0)
18: cll 'space'(-3)
19: cll 'skip'(1)
20: if G>E;gto +3
21: fmt 2,f4.0
22: wrt 701.2,G
23: next G
24: cll 'move'(.4*D,-.05*B)
25: wrt 701,"FREQUENCY-HERTZ"
26: for G=0 to B by .1*B
27: cll 'move'(C-.16*D,G)
28: fmt 4,e8.1
29: wrt 701.4,G
30: next G
31: cll 'move'(.05*D,B)
32: wrt 701,"ACCELERATION  G RMS"
33: cll 'move'(C,0)
34: for J=1 to 256
35: if D[2,J]>=C;gto +2
36: gto +3
37: cll 'fplt'(D[2,J],√(R*D[1,J]))
38: if D[2,J]>=E;gto +2
39: next J
40: dsp "DO YOU WANT ANOTHER PLOT"
41: wait 500
42: ent W
43: wtb r0,13
44: if W=1;gto 11
45: end

```



```

46: "move":
47: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
48: ret
49: "plt":
50: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
51: if p3=0;46→p3
52: if p3=46;wtb r0,27,82,0,0,0,6
53: wtb r0,p3;wtb r0,8
54: if p3=46;wtb r0,27,82,0,0,63,-6
55: ret
56: "fplt":
57: wtb r0,27,97,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
58: if p3=0;46→p3
59: if p3=46;wtb r0,27,82,0,0,0,6
60: wtb r0,p3;wtb r0,8
61: if p3=46;wtb r0,27,82,0,0,63,-6
62: ret
63: "psiz":
64: p1→H;p2→W
65: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
66: ret
67: "scl":
68: 120W/(p2-p1)→U
69: 96H/(p4-p3)→V
70: p1→X;p3→Y
71: ret
72: "xaxis":
73: wtb r0,27,46,95,0,5,9
74: if p3=0 and p4=0;X→p3;X+120W/U→p4
75: if p2=0;p4→p3→p2
76: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64)
,int((p1-Y)V)
77: p3→p5;wtb r0,43;wtb r0,8
78: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p
5+p2→p5)→p4
79: ret
80: "yaxis":
81: wtb r0,27,46,124,0,3,0
82: if p3=0 and p4=0;Y→p3;Y+96H/V→p4

```

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```
83: if p2=0;p4=p3+p2
84: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64)
,int((p3-Y)V)
85: p3+p5;wtb r0,43;wtb r0,8
86: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (p
5+p2+p5)>=p4
87: ret
88: "space":
89: if p1<0;gto +2
90: wtb r0,32;jmp 2((p1-1+p1)=0)
91: wtb r0,8;jmp (p1+1+p1)=0
92: ret
93: "skip":
94: if p1<0;gto +2
95: wtb r0,10;jmp 2((p1-1+p1)=0)
96: wtb r0,27,10;jmp (p1+1+p1)=0
97: ret
98: "form":
99: wtb r0,27,77
100: wtb r0,27,84
101: if p1=0;13.2=p1;11=p2+p3
102: wtb r0,27,87,int(120*p1/64),120*p1
103: wtb r0,27,76,int(96*p2/64),96*p2
104: wtb r0,27,70,int(96*p3/64),96*p3
105: ret
```

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DOUBLE AMPLITUDE PLOT PROGRAM

```
0: dim D[2,256]
1: 701→r0
2: 0→C;1000→E;1000→D;4.88→R
3: 384.6*√(2*R)/(2*π^2)→M
4: 0→Q;ldf 18,D[*]
5: for I=1 to 256
6: M*√D[1,I]/D[2,I]^2→L
7: if L≤Q;gto +2
8: L→Q
9: next I
10: 0→N
11: if Q>=1;gto +5
12: N+1→N
13: Q*10^N→P
14: if int(P)≠0;gto +9
15: gto -4
16: if Q>10;gto +3
17: Q→P
18: gto +5
19: N-1→N
20: Q*10^N→P
21: if P<10;gto +2
22: gto -3
23: (int(P)+(int(P)≠P))*10^(-N)→B
24: 100→F
25: cll 'form'(14,11,11)
26: cll 'psiz'(8,9,1,2)
27: cll 'scl'(C-.2*D,E,-.1*B,1.05*B)
28: cll 'xaxis'(0,F,C,E)
29: cll 'yaxis'(C,.1*B,0,B)
30: for G=C to E by F
31: cll 'move'(G,0)
32: cll 'space'(-3)
33: cll 'skip'(1)
34: if G>E;gto +3
35: fmt 2,f4.0
36: wrt 701.2,G
37: next G
38: cll 'move'(.4*D,-.05*B)
39: wrt 701,"FREQUENCY-HERTZ"
40: for G=0 to B by .1*B
41: cll 'move'(C-.16*D,G)
42: fmt 4,e8.1
```


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```

43: wrt 701.4,G
44: next G
45: cll 'move'(.05*D,B)
46: wrt 701,"DOUBLE AMPLITUDE-INCHES"
47: cll 'move'(C,0)
48: for J=1 to 256
49: if D[2,J]>=C;gto +2
50: gto +3
51: cll 'fplt'(D[2,J],M*sqrt(D[1,J]/D[2,J]^2)
52: if D[2,J]>=E;gto +2
53: next J
54: dsp "DO YOU WANT ANOTHER PLOT"
55: wait 500
56: ent W
57: wtb r0,13
58: if W=1;gto 25
59: end
60: "move":
61: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
62: ret
63: "plt":
64: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
65: if p3=0;46+p3
66: if p3=46;wtb r0,27,82,0,0,0,6
67: wtb r0,p3;wtb r0,8
68: if p3=46;wtb r0,27,82,0,0,63,-6
69: ret
70: "fplt":
71: wtb r0,27,97,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
72: if p3=0;46+p3
73: if p3=46;wtb r0,27,82,0,0,0,6
74: wtb r0,p3;wtb r0,8
75: if p3=46;wtb r0,27,82,0,0,63,-6
76: ret
77: "psiz":
78: p1+H;p2+W
79: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
80: ret
81: "scl":
82: 120W/(p2-p1)+U
83: 96H/(p4-p3)+V

```

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```

84: pl←X;p3←Y
85: ret
86: "xaxis":
87: wtb r0,27,46,95,0,5,9
88: if p3=0 and p4=0;X←p3;X+120W/U←p4
89: if p2=0;p4←p3+p2
90: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64)
,int((p1-Y)V)
91: p3←p5;wtb r0,43;wtb r0,8
92: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p
5+p2+p5)≥p4
93: ret
94: "yaxis":
95: wtb r0,27,46,124,0,3,0
96: if p3=0 and p4=0;Y←p3;Y+96H/V←p4
97: if p2=0;p4←p3+p2
98: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64)
,int((p3-Y)V)
99: p3←p5;wtb r0,43;wtb r0,8
100: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (
p5+p2+p5)≥p4
101: ret
102: "space":
103: if pl<0;gto +2
104: wtb r0,32;jmp 2((p1-1←p1)=0)
105: wtb r0,8;jmp (p1+1←p1)=0
106: ret
107: "skip":
108: if pl<0;gto +2
109: wtb r0,10;jmp 2((p1-1←p1)=0)
110: wtb r0,27,10;jmp (p1+1←p1)=0
111: ret
112: "form":
113: wtb r0,27,77
114: wtb r0,27,84
115: if p1=0;13.2←p1;11←p2+p3
116: wtb r0,27,87,int(120*p1/64),120*p1
117: wtb r0,27,76,int(96*p2/64),96*p2
118: wtb r0,27,70,int(96*p3/64),96*p3
119: ret

```

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DOUBLE AMPLITUDE LOG-LOG PLOT PROGRAM

```
0: dim D[2,256]
1: 701→r0
2: 1→C
3: 1000→E;4.88→R
4:  $384.6 \cdot \sqrt{(2 \cdot R) / (2 \cdot \pi^2)} \rightarrow M$ 
5: ldf 18,D[*]
6: cll 'form'(14,11,11)
7: cll 'psiz'(8,9,1,2)
8: cll 'scl'(-1,5,-6,1)
9: cll 'xaxis'(-5,1,0,4)
10: cll 'yaxis'(0,1,-5,0)
11: for G=0 to 4 by 1
12: cll 'move'(G,-5)
13: cll 'space'(-3)
14: cll 'skip'(1)
15: fmt 2,f4.0
16: wrt 701.2,G
17: next G
18: cll 'move'(1.5,-5.3)
19: wrt 701,"LOG FREQUENCY-HERTZ"
20: for G=-5 to 0
21: cll 'move'(-.2,G)
22: fmt 4,f2.0
23: wrt 701.4,G
24: next G
25: cll 'move'(2,0)
26: wrt 701,"DOUBLE AMPLITUDE LOG-INCHES"
27: for J=1 to 256
28: if D[2,J]<C; goto +4
29:  $M \cdot \sqrt{D[1,J] / D[2,J]^2} \rightarrow N$ 
30: cll 'plt'(log(D[2,J]),log(N))
31: if D[2,J]>E; goto +2
32: next J
33: cll 'move'(log(5.5),log(1e-5))
34: cll 'fplt'(log(5.5),log(1e0),46)
35: cll 'char'(46,2,6)
36: cll 'fplt'(log(38),log(2e-2),46)
37: cll 'fplt'(log(200),log(7.33432e-4))
38: cll 'fplt'(log(200),log(1e-5))
39: cll 'move'(log(33),log(8e-2))
40: wrt 701,"1.5G"
41: cll 'move'(log(500),log(1e-2))
42: wrt 701,"MIL-STD-810C-CURVE AW"
43: cll 'move'(log(500),log(1e-3))
44: wrt 701,"FOR EQUIPMENT CATEGORY 3"
45: dsp "DO YOU WANT ANOTHER PLOT"
```


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```
46: wait 500
47: ent W
48: wtb r0,13
49: if W=1;gto 6
50: end
51: "move":
52: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
53: ret
54: "plt":
55: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
56: if p3=0;46→p3
57: if p3=46;wtb r0,27,82,0,0,0,6
58: wtb r0,p3;wtb r0,8
59: if p3=46;wtb r0,27,82,0,0,63,-6
60: ret
61: "fplt":
62: wtb r0,27,97,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64)
,int((p2-Y)V)
63: if p3=0;46→p3
64: if p3=46;wtb r0,27,82,0,0,0,6
65: wtb r0,p3;wtb r0,8
66: if p3=46;wtb r0,27,82,0,0,63,-6
67: ret
68: "char":
69: if p2=0;5→p2;0→p3
70: wtb r0,27,46,p1,int(p2/64),p2,p3
71: ret
72: "psiz":
73: p1→H;p2→W
74: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
75: ret
76: "scl":
77: 120W/(p2-p1)→U
78: 96H/(p4-p3)→V
79: p1→X;p3→Y
80: ret
81: "xaxis":
82: wtb r0,27,46,95,0,5,9
83: if p3=0 and p4=0;X→p3;X+120W/U→p4
84: if p2=0;p4-p3→p2
85: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64)
,int((p1-Y)V)
```

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```
86: p3→p5;wtb r0,43;wtb r0,8
87: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p
5+p2→p5)>=p4
88: ret
89: "yaxis":
90: wtb r0,27,46,124,0,3,0
91: if p3=0 and p4=0;Y→p3;Y+96H/V→p4
92: if p2=0;p4→p3→p2
93: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64)
,int((p3-Y)V)
94: p3→p5;wtb r0,43;wtb r0,8
95: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (p
5+p2→p5)>=p4
96: ret
97: "space":
98: if p1<0;gto +2
99: wtb r0,32;jmp 2((p1-1→p1)=0)
100: wtb r0,8;jmp (p1+1→p1)=0
101: ret
102: "skip":
103: if p1<0;gto +2
104: wtb r0,10;jmp 2((p1-1→p1)=0)
105: wtb r0,27,10;jmp (p1+1→p1)=0
106: ret
107: "form":
108: wtb r0,27,77
109: wtb r0,27,84
110: if p1=0;13.2→p1;11→p2→p3
111: wtb r0,27,87,int(120*p1/64),120*p1
112: wtb r0,27,76,int(96*p2/64),96*p2
113: wtb r0,27,70,int(96*p3/64),96*p3
114: ret
```

APPENDIX C. REFERENCES

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